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Research Article

Functional passive range of motion of individuals with chronic cervical spinal cord injury

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Objective: Functional passive range of motion (PROM) requirements for individuals with cervical spinal cord injury (SCI) are clinically accepted despite limited evidence defining the specific PROM needed to perform functional tasks. The objective of this investigation was to better define the minimum PROM needed for individuals with cervical SCI to achieve optimal functional ability, and as a secondary outcome gather self-reported standardized functional data via the Spinal Cord Independence Measure-III (SCIM-III), and the Spinal Cord Injury Functional Index (SCI-FI).

Design: Observational cohort.

Setting: 128-bed rehabilitation hospital with inpatient and outpatient spinal cord injury rehabilitation programs.

Participants: A convenience sample of 29 community-dwelling individuals with chronic (greater than one year) tetraplegic SCI (C5-8) who use a wheelchair for mobility.

Interventions: None.

Outcome measures: Therapist goniometric measurement of upper and lower extremity PROM, and participant completion of a demographic questionnaire and two functional self-report measures (SCIM-III and SCI-FI) were completed.

Results: Compared to the general population, differences observed in our study participants included limitations in forearm pronation and elbow extension and increased shoulder extension and wrist extension (likely related to prop sitting). Elbow hyperextension was noted in one-third of the participants. Limitations in straight leg raise, hip flexion, abduction, and internal rotation, in combination with increased hip external rotation suggested these individuals with cervical SCI potentially completed activities of daily living (ADLs) in frog-sitting, rather than long-sitting. Ankle plantarflexion contractures were found in many participants. Shoulder horizontal adduction, elbow extension, hip flexion, knee flexion, ankle plantarflexion, and forefoot eversion ROM were associated with functional performance.

Conclusion: Based on our results healthcare providers should work with individuals with cervical SCI to develop long term PROM plans to optimize functional abilities.

Keywords: Cervical spinal cord injury, Tetraplegia, Range of motion, Spinal cord injury, Upper extremity, Occupational therapy, Physical therapy, Rehabilitation, Contracture

Introduction

There is limited evidence defining the minimum passive range of motion (PROM) requirements needed by individuals with cervical spinal cord injury (SCI) to perform functional tasks. Currently, clinicians must rely on an understanding of functional PROM needed to complete activities based on knowledge gained from clinical experience, which can vary widely. For example, clinicians may question the minimum amount of hip flexion required to successfully complete lower body dressing in long sitting, or the degree to which elbow joint restriction impacts the ability to lock the elbow in extension for transfers. In the current healthcare environment, clinicians must prioritize limited treatment time to obtain the optimal client outcomes. Better

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understanding of the PROM needed to perform functional skills will inform clinicians how to effectively allocate treatment time.

No empirical data exist to guide practitioner understanding what range of motion (ROM) is required for individuals with cervical SCI to optimize functional outcomes. The normative PROM for individuals with SCI values currently taught and clinically utilized originated from non-SCI population data.[1] However, PROM limitations are prevalent and observed in 9-70% of individuals with SCI with the most common limitations occurring at the shoulder, elbow, and ankle.[2–12] Multiple factors are associated with PROM limitations including: an extended acute care hospitalization, concurrent traumatic brain injury (TBI), spasticity, heterotopic ossification (HO), shoulder pain, and age.[2–11]

Diong *et al*. measured PROM within 35 days of SCI and 1 year later using a subjective 4-point scale and found an 11–43% contracture incidence after 1 year, most commonly affecting the ankle, wrist, and shoulder.[2] Eriks-Hoogland *et al.* reported 70% of individuals with tetraplegia and 29% of those with paraplegia experienced limited shoulder PROM during inpatient rehabilitation, and at one year after injury.[3] External rotation deficits were most likely to develop during inpatient rehabilitation and shoulder flexion deficits developed after discharge. Increased age, tetraplegia, spasticity of elbow extensors, longer duration between injury and start of active rehabilitation, and the presence of shoulder pain was associated with decreased shoulder PROM.

In a sample of 43 individuals with tetraplegia, Bryden *et al.* demonstrated that 46% of individuals with C5 SCI and 63% of those with C6 SCI lacked full elbow extension, indicating individuals with denervated triceps are at serious risk for development of elbow contractures.[4] Salisbury *et al.* described 41 people with tetraplegia who lost shoulder flexion, abduction, and external rotation (at 90° abduction) ROM and experienced concurrent shoulder pain; individuals with a history of previous shoulder injuries were at a higher risk for developing shoulder ROM deficits.[5] Dalyan *et al*. studied 482 inpatients and found 9% developed contractures during inpatient rehabilitation that were most commonly associated with pressure ulcers, spasticity and concurrent TBI.[6]

Research showing the functional implications of ROM limitations is also limited. Eriks-Hoogland *et al*. reported an association between shoulder pain and reduced shoulder PROM and a tetraplegia diagnosis in a 5-year longitudinal study of 225 individuals with SCI but the functional implications of these limitations were not analyzed.[13] After a literature review of 18 kinematic studies, Mateo *et al.* hypothesized limited active ROM observed during overhead reaching could be caused by shoulder joint ankyloses or shoulder pain.[14]

Harvey and Herbert published a guide on common contractures in SCI and positional strategies for prevention.[12] They proposed that individuals with C5 injuries and above are at highest risk for contracture but identified risks for all levels of SCI. Common areas for upper extremity were hypothesized to be shoulder flexion/abduction/external rotation, elbow extension, forearm pronation/supination, wrist flexion, MCP flexion, IP extension and thumb abduction. Common lower extremity limitations were hip extension/adduction, hip flexion with knee extension, knee extension, and ankle dorsiflexion.

Methods

This study examined PROM in a convenience sample of 29 individuals with cervical SCI. Individuals with C5-8 SCI who demonstrated some functional use of their upper limbs and relied on a wheelchair for their daily mobility were eligible to participate. Participants were recruited via outpatient clinics, adapted sports programs, and support groups at a 132-bed freestanding rehabilitation facility with comprehensive inpatient and outpatient SCI programs. In this pilot study participants completed a demographic questionnaire, the Spinal Cord Independence Measure-III (SCIM-III), and the Spinal Cord Injury Functional Index (SCI-FI).[15,16] The SCIM-III is an established scale developed to address the ability of individuals with SCI to perform basic activities of daily living. The SCI-FI is a newer instrument that allows the individual to rate their performance on specific tasks related to daily life. The paper and pencil forms of both these instruments were used. Because the paper and pencil form of the SCI-FI is not easily assessed in aggregate, the subsection scores were used for this project. Passive ROM was measured according to the guidelines published in Bandy and Reese's Joint Range of Motion and Muscle Length Testing textbook once for each of the movements found in Tables 1 and 2. The participants were tested in supine by one of two skilled clinicians with over ten years of clinical experience in SCI.[17] The two clinician ROM measurements demonstrated inter-rater reliability within 5 degrees for all study measurements on two subjects with SCI who were not participants in the study. For the purposes of this study elbow and knee hyperextension is listed as a positive value, and limitations in extension are documented as a negative value (degrees lacked from full extension or 0°). For any motion where the participant was unable to reach

Table 1 Upper extremity passive range of motion means and ranges by level of injury (absolute values).

Motion	General Population	SCI	Range	C5	C6	C7-8
Shoulder Extension	60	72.4	44–95	72.21	73.04	71.61
Shoulder Flexion	165	155.33	88–185	148.79	156.15	159.22
Shoulder Abduction	170	175.41	71–201	169.07	173.38	183.28
Shoulder Horizontal Adduction	120	122.57	94–142	113.43	125.04	126.11
Shoulder External Rotation (Humerus abducted to 90)	90	82.16	32–107	81.79	80.15	79.38
Shoulder External Rotation (Humerus Adducted)	90	85.60	41–119	82.29	85.85	87.83
Shoulder Internal Rotation	70	70.05	22–99	79.07	67.35	66.94
Elbow Extension	0	−6.21	−64-30	−11.14	−0.54	−10.56
Elbow Flexion	140	144.02	124–155	147.64	143.54	141.89
Forearm Pronation	80	65.86	−31-92	51.71	69.15	72.11
Forearm Supination	80	80.38	−5-114	84.86	82.42	73.94
Wrist Extension	70	79.14	40–110	75.79	79.12	81.78
Wrist Flexion	80	81.21	40–110	84.57	78.50	82.50
Wrist Radial Deviation	20	19.84	−10-41	18.50	19.88	20.83
Wrist Ulnar Deviation	30	30.86	2–57	29.21	29.96	31.17

the neutral, or starting position, the value was listed as a negative.

Statement of ethics. We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research.

Data analysis. All data were entered in to Microsoft Excel for storage and management, then exported to SPSS version 22 for analyses. Analyses included descriptive statistics, bivariate correlations, and independent means t-tests with statistical significance set at $P \leq 0.05$. Bivariate correlations relied on Spearman Rho coefficients due to the ordinal nature of the variables.

Results

Demographic data. 30 participants were enrolled, 27 men and 2 women completed the study; one participant withdrew prior to ROM evaluation and was not included in the analysis. Ages ranged from 21 to 64 (mean 42.3) years. The participants' racial distribution included 14 Black, 13 White, 1 Hispanic, and 1 Native American. Time since injury varied from 1.17 to 40 years with a mean of 11.64 years. Injury cause was traumatic for 27 participants and non-traumatic for 2. The participants' International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) classification are listed in Table 3. All but one participant self-reported spasticity, and all but 3 stated spasticity medication was used. Mobility characteristics included twelve manual wheelchair and 17 power wheelchair users. Twenty-one participants reported completing home ROM exercises including passive, active, and active assist completed at an average of 3.41 times per week with 17 responding self ROM comprised their entire home ROM exercise. Twenty-one individuals also completed strengthening exercises on a regular basis with an average frequency of 3.33 times per week.

ROM analysis: Absolute ROM assessment revealed notable differences between individuals with cervical SCI and the general population normative data (Tables 1 and 2). Upper Limb: Shoulder extension was greater in this study population than the general

Table 2 Lower extremity passive range of motion means and ranges by level of injury (absolute values).

Motion	General Population	SCI	Range	C5	C6	C7-8
Straight Leg Raise	100	76.52	35–112	64.71	77.69	84.00
Hip Extension	20	−8.34	−36-20	−8.43	−0.50	−6.28
Hip Flexion	120	110.09	61–142	97.29	114.38	113.83
Hip Abduction	45	32.07	3–90	34.00	28.42	35.83
Hip Adduction	25	23.07	10–41	24.43	20.27	26.06
Hip External Rotation	40	50.07	17–78	46.57	51.81	52.61
Hip Internal Rotation	45	30.64	6–64	30.14	28.81	33.67
Knee Extension	0	−5.84	−25-0	3.50	4.73	9.28
Knee Flexion	140	131.55	92–152	123.57	133.38	135.11
Ankle Dorsiflexion	20	−11.88	−34-18	−10.21	−9.69	−9.67
Ankle Plantar Flexion	50	43.91	18–72	46.07	46.58	38.39
Foot Inversion	35	25.10	0–40	23.79	26.46	24.17
Foot Eversion	20	17.07	−10-30	17.64	16.27	17.78

Table 3 Demographics by level of injury and AIS classification.

Level	C5	C6	C7	C8	Total
AIS A	4	4	2	0	8
AIS B	0	2	2	0	4
AIS C	3	6	4	1	14
AIS D	0	1	0	0	1
Total	7	13	8	1	29
	C5	**C6**	**C7/8**		**Total**
Age (years)	46.0 ± 15.25	40.85 ± 12.39	40.78 ± 11.10		42.01 ± 12.46
Male (%)	85.71%	100%	88.89%		93.1%
Time since injury (years)	13.42 ± 12.39	7.35 ± 6.83	16.48 ± 13.21		11.65 ± 10.92

able-bodied population. Elbow extension limitations were prevalent, but of those who could achieve full extension, hyperextension was observed in 10 participants. Wrist extension was greater in the sample population than the general population. Lower Limb: Straight leg raise (SLR) hip flexion, abduction, and internal rotation fell short of the documented ranges for the able-bodied population. Ankle plantarflexion contractures were ubiquitous with the mean being over 10 degrees less than neutral and 23 participants unable to achieve a neutral position in one or both ankles.

The relationship between PROM and function. A Spearman's Rho correlation examined the relationship between functional skills and PROM ($P \leq 0.05$). *Upper limb*: Shoulder horizontal adduction displayed a significant association with the most functional tasks (Table 4). Significant associations were found between horizontal adduction and overall ADL and mobility status as measured by the SCIM-III and the SCI-FI subsections, as well as the SCIM-III feeding, dressing, and bathing domains. Elbow extension was associated with overall SCIM-III scores and the lower body bathing subtest. Shoulder flexion was associated with SCIM-III Feeding ($P = 0.029$), and shoulder abduction was associated with SCIM-III grooming ($P = 0.046$). Wrist ulnar deviation was associated with lower body bathing ($P = 0.035$). *Lower limb*: The most significant lower extremity correlations arose from hip and knee flexion, where greater PROM was associated with improved performance in ADLs and mobility as measured by the SCIM-III, as well as a large majority of the subtests (see Table 4). Interestingly, hip and knee flexion ROM increased with lower injury levels (Table 2). Additional associations included both straight leg raise, ($P = 0.037$) and forefoot inversion ($P = 0.049$) with SCIM-III Grooming.

T-tests examined differences between individuals who were independent in ADLs compared to those not independent in ADLs as defined by requiring no assistance for items 1–4 on the SCIM-III ADL subsection. Significantly higher PROM for shoulder horizontal adduction, hip flexion, hip internal rotation, and knee flexion were seen for individuals who are independent in their ADLs.

T-tests also determined the existing PROM differences between manual and power wheelchair users. Significant differences were seen for shoulder horizontal adduction, wrist ulnar deviation, hip flexion, and knee flexion, and power wheelchair users exhibited greater limitations than manual wheelchair users.

Table 4 Spearman's rho correlation coefficients and associated P values.

	Shoulder horizontal adduction	Elbow extension	Hip flexion	Knee flexion	Ankle Plantarflexion	Forefoot Eversion
SCIM-III total	0.496**	−0.388*	0.292	0.462*	−0.275	0.332
SCIM-III mobility	0.610***	−0.277	0.368*	0.508**	−0.315	0.180
SCIM-III ADL	0.574**	−0.233	0.541**	0.593**	−0.380*	0.309
SCIM-III feeding	0.491**	−0.234	0.325	0.429*	−0.103	0.201
SCIM-III grooming	0.471*	−0.262	0.418**	0.394*	−0.315	0.165
SCIM-III upper body bathing	0.435*	−0.268	0.469*	0.457*	−0.122	0.172
SCIM-III lower body bathing	0.288	−0.367*	0.610***	0.477**	−0.436*	0.434*
SCIM-III upper body dressing	0.412*	−0.083	0.542**	0.501**	−0.359	0.190
SCIM-III lower body dressing	0.298	−0.035	0.454*	0.487**	−0.367*	0.372*

*P < 0.050, ** P < 0.010, *** P < 0.001.

Discussion

This is the first study to describe typical PROM in people with cervical SCI. Contractures were prevalent among the study participants, even though the sample consisted of active community-dwelling individuals with the majority engaging in regular strength and ROM exercises. We measured PROM using standardized methods in supine to minimize the confounding effect of compensatory positions and ROM in adjacent joints that some individuals use during functional activities. One inherent limitation of goniometry is that only a single joint can be measured at a time; however, kinematic studies that simultaneously track multiple joints using skin markers have demonstrated that a variety of joint movements can be utilized to perform a given functional task. This apparent limitation may be an advantage in isolating joint ROM and is more widely available in clinical practice. Many of the subjects demonstrated independence with ADLs and functional mobility despite PROM limitations.

Adapting to cervical SCI and maximizing function can strain joints. Shoulder hyperextension is required for "prop-sitting," to position the upper limb behind the torso for sitting stability. Elbow hypermobility/hyperextension may be linked to locking out the elbows for prop-sitting and transfers. Interestingly, eight participants with elbow extension limitations were able to achieve independence in transfers. Horizontal adduction contributes greatly to performing ADL functions as the ability to reach the arm across the body impacts all areas of ADL performance. There is a resultant increase in horizontal adduction with lower level injuries as pectoralis innervation increases. Increases in shoulder flexion with feeding and shoulder abduction with grooming are likely associated with the need to reach forward to the mouth and laterally to the face and head for these tasks, respectively.

Forearm pronation and supination is critical for ADL performance as these motions position the hand in an optimal position for bimanual or tenodesis-based tasks. In addition, limited forearm mobility puts an increased burden on shoulder muscles as shoulder abduction substitutes for forearm rotation which may contribute to the high incidence of shoulder pain in individuals with SCI.[18] It is important to remember the musculature required for forearm movement is not innervated at higher levels of cervical SCI and, as expected, the amount of pronation increased as the level of SCI moved caudally.

Wrist extension hypermobility appears related to the tendency for individuals with cervical SCI to continuously bear weight through the wrist for function. Indeed, wrist extension hypermobility was highest in the subset of individuals with C6-8 levels of injury who demonstrated greater independence and participation in daily transfers and other mobility tasks than individuals with higher injuries. The association between ulnar deviation and LB bathing may be incidental, but perhaps ulnar deviation increases for individuals with tetraplegia completing lower body tasks as they press through their wrist which has stronger innervation at the radial side at the C6 level of injury.

Anecdotal clinical experience recommends an individual with cervical SCI requires a straight leg raise (SLR) of 120 degrees to complete long sitting activities of daily living (ADLs). The actual SLR measured in the study population measured much less at 76.52 degrees. SLR does increase with lower level of injury and more functional mobility, but this finding, in conjunction with concomitant hip external rotation hypermobility suggests individuals with SCI are not completing ADLs in long sitting, but rather using a frog-sitting posture. Hip flexion, abduction, and internal rotation also fell short of the recommended required ranges. It is possible these motions may not be essential to completing ADLs.

The association of hip PROM with ADL performance with tabletop tasks highlights the importance of pelvic position upon function. The pelvis serves as the base of stability for ADL performance. Limitations in hip mobility can lead to sub-optimal pelvic positioning, sacral sitting, a kyphotic posture, and forward head position can limit active reach at the shoulder and functional use of the upper limb. In our client population, hip flexion limitations were prominent and observed in 24 of the participants. To counteract this ROM loss, daily prone positioning is required to support optimal pelvic alignment. Standing frame use could also stretch the pelvis, knee, and ankle for those who are medically able to tolerate standing. Neutral or close to neutral pelvic alignment, or a stable base, is needed to complete functional activities. The association between forefoot inversion and grooming may be incidental or may further support the need for a stable sitting posture for tabletop activities. Foot flat positioning offers an assist to a neutrally positioned pelvis to provide a stable platform for upper body activities. Plantarflexion contractures were prevalent, but some individuals with tight plantarflexion in supine may be able to achieve foot flat in their wheelchair when the knee is flexed which may be why the functional impact of this limitation is not observed.

Clinicians who work with individuals with tetraplegia should educate individuals and their caregivers to constantly monitor ROM limitations and their impact on functionRegular outpatient therapy maintenance evaluations may prevent ROM limitations and guide individuals with cervical SCI to develop a sustainable plan to maintain their flexibility and resultant function. A recent Cochrane review indicates that stretching may not improve ROM limitations so positional strategies and activity modifications should be emphasized during therapy sessions.[19] Regular seating system evaluations are also recommended to accommodate any ROM limitations that may develop over time. Clinicians are encouraged to assess ROM during seating evaluations and prescribe home exercise and ROM programs as needed and provide appropriate outpatient clinic referrals to address new or increasing limitations.

Study limitations include the use of a convenience sample composed exclusively of participants living in the community, with no inclusion of individuals residing in subacute or long-term care facilities. Furthermore, all participants held and utilized accessible transportation. These two factors may create a cervical SCI subset demonstrating more robust PROM values. All functional skill data utilized self-reported scales which are valid clinical tools but in future studies data triangulation by caregiver input is suggested. It is also unclear if our weak to moderate associations between PROM and the self-reported ADL activities were impacted by a small pilot study cohort.

Future research recommendations include expanding the range of motion and function investigation scope. One suggestion is to include multiple geographic areas to provide more data from each injury level and facilitate a more detailed statistical analysis among subgroups such as level of injury and other demographic variables. A description of ROM and functional abilities of individuals residing in long-term care facilities may provide insight and direct ongoing care. The ROM between individuals with SCI residing in the community could be compared with those residing in long-term care facilities. Additionally, ROM related to functional abilities could be assessed by tallying daily care hours required and determine if a relationship exists with passive ROM. The impact of pain on range of motion should be examined. The relationship between ROM and positional splints and brace use would provide information on the effectiveness of these devices. Comparison of active and passive range of motion with kinematic analysis and/or strength testing and dynamometry, could increase understanding of specific physical attributes necessary to achieve optimal function. Finally, longitudinal investigation of how ROM and function change over time could guide more effective ROM re-education and intervention. Such a study might incorporate kinematic analysis and examine differences in how exercise impacts ROM when it is completed independently, with caregiver assistance, using rehabilitation technology, or in an outpatient setting with a skilled therapist.

Conclusion

This observational study identified significant ROM differences in individuals with cervical SCI when compared to the general population and associated these with their self-reported performance of functional tasks. Some of these range of motion differences can be associated with enhanced functional performance [or the residue of optimization], while others may be maladaptive. Achievement of optimal function and quality of life with cervical SCI requires effective ROM during rehabilitation and throughout the lifespan

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